

PARASITOIDS OF THE AUTUMN GUM MOTH, *MNESAMPELA PRIVATA* (GUENÉE) (LEPIDOPTERA: GEOMETRIDAE) IN SOUTH-EASTERN AUSTRALIA, WITH DESCRIPTION OF TWO NEW LARVAL PARASITOIDS

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Summary

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Parasitoids were reared from cocoons present in larval shelters of *Mnesampela privata* (Guenée) collected at Altona and Shepparton, Victoria and Canberra (Lyneham Ridge), ACT. The most common primary parasitoid was a gregarious braconid wasp, described here as *Cotesia geometricae* Austin sp. nov. This species attacked host larvae at all locations and emerged from the fourth or fifth instar, pupating gregariously. A second braconid, described here as *Glyptapanteles mnesampela* Austin sp. nov., was found at Lyneham Ridge. This parasitoid was superficially similar to *C. geometricae*, attacked early-instar host larvae and also emerged from the fourth or fifth instar to pupate gregariously. One other solitary primary parasitoid, *Casinarina micra* Jerman & Gauld (Ichneumonidae), emerged from fourth or fifth instar larvae and pupated externally. At least five species of hyperparasitoids emerged from the cocoons of *C. geometricae* collected in Victoria: two species of *Isdromus* (Ichneumonidae), *Mesochorus* sp. (Ichneumonidae), *Elasmus* sp. (Elasmidae) and *Megadicylus* sp. (Pteromalidae), with one of the *Isdromus* species being most common. The larval-pupal parasitoid *Heteropelma scaposum* (Morley) (Ichneumonidae) emerged from 10% of pupae reared from larvae collected in the ACT over the same period as adults of *M. privata*. Sex and viability significantly influenced the weight of pupae of *M. privata* but pupae parasitised by *H. scaposum* could not be separated using weight. Notes and an illustrated key are provided to facilitate the easy identification of the parasitoids.

KEY WORDS: Autumn gum moth, *Mnesampela privata*, Geometridae, *Glyptapanteles*, *Cotesia*, *Casinarina*, *Heteropelma*, *Isdromus*, *Mesochorus*, *Elasmus*, *Megadicylus*, Braconidae, Ichneumonidae, Elasmidae, Pteromalidae.

Introduction

The autumn gum moth, *Mnesampela privata* (Guenée) (Geometridae) is endemic to Australia and occurs throughout the south-eastern and south-western parts of the continent as well as Tasmania (McQuillan 1985; Abbott 1993). Larvae feed on a wide range of eucalypt species (McQuillan 1985) but prefer the juvenile foliage of trees in the blue gum group (Elliott & Bashford 1978), which includes the important plantation species *Eucalyptus nitens* (Deane & Maiden) Maiden and *E. globulus* Labill. (Abbott 1993; Bashford 1993; Neumann 1993; Phillips 1993). *Mnesampela privata* can occur in high numbers in young, even-aged stands of planted eucalypts and cause severe defoliation (Elliott &

Bashford 1978; Roberts & Sawtell 1981; Elliott *et al.* 1990; Abbott 1993; Neumann 1993; Phillips 1993; Farrow *et al.* 1994). Outbreaks can be economically costly as severe defoliation can reduce the growth of trees (Floyd & Farrow 1994) and may eventually kill them if defoliation occurs over several successive years (Carme *et al.* 1974).

Currently, management of outbreaks of *M. privata* consists of broad-scale spraying with non-specific chemical insecticides (de Little 1981; Elliott *et al.* 1990; Neumann 1993; Phillips 1993; Neumann & Collett 1997). These chemicals have undesirable effects on the environment, may exacerbate outbreaks of *M. privata* and other defoliators by eliminating natural enemies and may induce insecticide resistance (Huffaker 1980; Risch 1987; Neumann 1992). Alternative pest management techniques such as biological control, target-specific chemicals and silvicultural methods have the potential to minimise environmental damage and contribute to sustainable management practices (Huffaker 1980; Ohmart 1990; Floyd & Farrow 1994). However, successful implementation of any pest management programme requires a thorough knowledge of the ecology of the pest and its natural enemies (Ohmart 1990). Despite the importance of

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DE LITTLE, D. W. (1981) A study of the autumn gum moth, *Mnesampela privata* Guen. (Lepidoptera: Geometridae) on *Eucalyptus nitens* in north west Tasmania. Associated Forest Holdings, Internal Report, Hobart (unpub).

M. privata as a pest there have been few studies of its biology (e.g. Elliott & Bashford 1978; de Linde 1981; Lukacs 1999) and information concerning its parasitoids is fragmentary.

The aim of this study was to identify parasitoids and hyperparasitoids associated with the larvae of *M. privata* in the ACT and Victoria, conduct an investigation of parasitoid host age preference and examine the influence of sex, viability and parasitism on the pupal weight of *M. privata*. A key to the parasitoid species reared in this study is given and two new braconid species, *Cotesia geometricae* Austin sp. nov. and *Glyptapanteles mnesampela* Austin sp. nov. are described.

Materials and Methods

Study sites

The study was undertaken at two sites in Victoria in September 1992 and one in the ACT during late autumn and winter 1993 and 1994. The sites in Victoria comprised a plantation of *E. globulus globulus* at Altona (37° 50' S, 144° 48' E), and a farm planting at Shepparton (36° 20' S, 145° 13' E) comprising *E. g. globulus*, *E. g. pseudoglobulus* and *E. g. bicostata*. Both locations had heavy infestations of *M. privata* (up to 100% defoliation by larvae). The ACT site was at Lynham Ridge, Canberra (35° 14' S, 149° 6' E), comprising mixed eucalypt species which were only lightly infested by *M. privata* (approximately 10% defoliation by larvae).

Rearing parasitoids

Parasitoids were reared from late-instar larvae of *M. privata*, the former having pupated in the leaf-bag in which host larvae shelter during the day (Elliott & Bashford 1978; McQuillan 1985). Leaf-bags containing late-instar host larvae and parasitoid cocoons were collected from 44 *E. g. globulus* at Altona, and approximately 10 trees (comprising *E. g. globulus*, *E. g. pseudoglobulus* and *E. g. bicostata*) at Shepparton. One leaf-bag containing late-instar larvae and parasitoid cocoons was collected from *E. g. bicostata* at Lynham Ridge in late August 1994.

Each parasitoid cocoon (or group of cocoons that were spun together in the instances of multiple parasitism) was trimmed from the leaf-bag, placed in a ventilated vial (2 cm diam. x 8 cm high) and incubated at 20 ± 2°C. Approximately 130 such samples resulted from material collected from Altona, 13 from Shepparton and one from Lynham Ridge. Vials were checked weekly until parasitoids began to emerge and then every 1–3 days for two

weeks. A final check was made after 18 days. Adult parasitoids were removed as they emerged and placed in 70% ethanol.

Host age preference

To investigate the host age preference of larval parasitoids, a range of available instars was collected from *E. g. bicostata* at Lynham Ridge on eight occasions in 1993. Collections were made 2–3 weeks apart, over the period that larvae were present (early May to late August). On each occasion 2–12 trees were inspected and groups of 1–19 (median of 5.5) larvae collected from each tree. Larvae were reared in ventilated plastic containers (120 mm diam. x 95 mm high), provided with a small branch of juvenile *E. g. bicostata*, the stem of which was placed through a hole in the base of the container and into water below. Foliage was changed twice weekly. Larvae were reared at 25 ± 2°C under natural light conditions. When larvae or pupae of parasitoids were observed with a dead or dying *M. privata* larva, the date, number of parasitoids present and the instar of the host larva were recorded. Larvae that died for reasons other than parasitisation were not included in the analysis. Head capsule size was used to estimate the larval instar of *M. privata* (Elliott & Bashford 1978). Parasitoid larvae or pupae were removed to individual ventilated vials (2 cm diam. x 8 cm high) and incubated at 22 ± 2°C until the adults emerged. Adults were stored in 70% ethanol.

Pupal weight

Mnesampela privata larvae collected from Lynham Ridge that pupated successfully were weighed within three days of pupation. Each pupa was incubated in a ventilated vial (20 mm diam. x 80 mm high) at a temperature of 4.0 ± 0.5°C and 70% relative humidity until late October. In November, pupae were placed outside in natural light and temperature regimes and relative humidity was maintained at 70%. Pupae were inspected monthly from mid-January for the emergence of parasitoids or adult *M. privata*. Parasitoids emerging from host pupae were stored in 70% ethanol. The sex of adult *M. privata* was determined using the morphology of the frenulum (after Elliott & Bashford 1978) and that of non-viable pupae by the position of the genital scar (Lawrence *et al.* 1991). One-way ANOVA was performed to test if the outcome of pupae of *M. privata* (i.e. the emergence of either a male or female adult *M. privata*, an adult parasitoid or the death of the pupae) influenced weight at pupation (Sokal & Rohlf 1981), with significantly different groups separated by Scheffé's test of multiple contrasts (Zar 1984). A chi-square goodness-of-fit test was used to compare the sex ratios of pupae and adults with an expected ratio of 1:1 (Sokal & Rohlf 1981).

¹ FLOYD, Z. (1999) Phenology of the autumn gum moth *Mnesampela privata* (Cresson). PhD thesis, University of Tasmania (unpub.).

Pearson's chi-square was performed to determine if successful pupation to adult was independent of the sex of the pupa (Sokal & Rohlf 1981).

Results

Parasitoid complex

Cocoons formed by two species of primary parasitoids were present in the leaf-bags collected at Altona and Shepparton (Table 1). The most common cocoon, made by *Cotesia geometricae* (Braconidae), was white, about 4 mm in length and found in groups spun together with silk. The other type of cocoon, formed by *Casinaria micra* Jermin & Gauld (Ichneumonidae), was mottled orange-brown, about 6 mm in length and solitary. Five species of hyperparasitoids emerged from the cocoons of *C. geometricae* (Table 1), the most numerous being a species of *Isdromas* (Ichneumonidae) (hereafter referred to as *Isdromas* species A). A second species of *Isdromas* (*Isdromas* species B), *Megadicylus* sp. (Pteromalidae), *Mesochorus* sp. (Ichneumonidae) and *Elasmus* sp. (Elasmidae) also emerged from the cocoons of *C. geometricae*. *Cotesia geometricae* also emerged from cocoons present in the leaf-bag collected at Lyneham Ridge in 1994. However, *C. geometricae* was not reared from larvae collected at Lyneham Ridge in 1993. Instead, another braconid, *Glyptanteles mnesampela*, pupated in groups of one or two white cocoons external to the late-instar host (Table 2). *Casinaria micra* was also reared from a larva collected at Lyneham Ridge in 1993 and the larval-pupal parasitoid, *Heteropelma scaposum* (Morley) (Ichneumonidae) emerged from the pupae of *M. privata* reared over the summer of 1993-94.

Relative frequency of parasitoids reared from parasitoid cocoons present in leaf-bags

Of the 130 samples collected from Altona, 69 resulted in the emergence of *C. geometricae* and/or its hyperparasitoids (536 individuals) and 10 with *C. micra* (Table 1), while 51 did not yield any parasitoids. The 13 samples from Shepparton resulted in four without emergence, four with *C. geometricae* and/or its hyperparasitoids (17 individuals) and five with *C. micra*. The single sample collected in 1994 at Lyneham Ridge yielded 14 individuals of *C. geometricae*. The cocoons in each group of *C. geometricae* were not counted or examined closely for prior emergence, so it was not possible to determine the average number of cocoons per group based on the number that emerged, or to calculate accurately the relative frequency of successful emergence, non-viability and hyperparasitisation. Bearing this in mind, about one-third of the groups of *C. geometricae* cocoons resulted in the exclusive emergence of *C. geometricae*, one-third resulted in an initial emergence of *C. geometricae* followed by the emergence of *Isdromas* sp. A from the remainder of the cocoons (N.B. six of these groups also yielded *Isdromas* sp. B, *Megadicylus* sp. and *Mesochorus* sp. after an initial emergence of *C. geometricae*), and one-third exclusively yielded hyperparasitoids, *Isdromas* sp. A, *Isdromas* sp. B, *Megadicylus* sp. and *Mesochorus* sp. emerged from cocoons collected at Altona, and *Isdromas* sp. A and *Elasmus* sp. from Shepparton (Table 1). Thus, at the two sites in Victoria, *C. geometricae* was the most frequent primary parasitoid of larvae but about half of its cocoons were hyperparasitised, primarily by *Isdromas* sp. A.

TABLE 1. Parasitoid species emerging from cocoons associated with the larvae of *Mnesampela privata* collected in Altona and Shepparton, Victoria in 1992. *Total number of cocoons per group was not counted.

Cocoon type	Biology	Species emerged	Altona		Shepparton	
			No. individuals	% of total No. individuals	No. individuals	% of total No. individuals
White, gregarious	Primary parasitoid	<i>Cotesia geometricae</i>	252	47.0	4	23.6
		Hyperparasitoid	<i>Isdromas</i> sp. A	246	45.9	10
	-	<i>Mesochorus</i> sp.	18	3.4	0	-
	-	<i>Isdromas</i> sp. B	11	2.1	0	-
	-	<i>Megadicylus</i> sp.	9	1.7	0	-
	-	<i>Elasmus</i> sp.	0	-	3	17.7
	-	Total No. individuals	536	-	17	-
	*Median No. of emergences/group	6	-	4	-	
Orange, solitary	Primary parasitoid	<i>Casinaria micra</i>	10	-	5	-

TABLE 2. Parasitisation of larvae of *Mnesampela privata* collected at Lyneham Ridge (Canberra, ACT) in 1993. ^aIn 1994 *Cotesia geometricae* was reared from parasitoid cocoons present in a *M. privata* leaf-bag.

<i>M. privata</i> collection		Parasitoid emergence			
Date	Instar	Date	Host instar	No. emerged	Parasitoid species
2/05/93	2	22/06/93	4	1	<i>Glyptapameles mnesampela</i>
2/05/93	2	22/06/93	4	2	<i>G. mnesampela</i>
16/05/93	3	22/06/93	4	1	<i>G. mnesampela</i>
2/07/93	4	11/07/93	5	1	<i>Casinarina micra</i>

Casinarina micra occurred less frequently and did not appear to have any hyperparasitoids. Estimates of the relative frequency of larval parasitoids at Lyneham Ridge in 1994 could not be made as only a single sample was collected and a comprehensive survey was not undertaken.

Relative frequency of parasitoids reared from collected larvae of M. privata

The 426 larvae of *M. privata* collected at Lyneham Ridge in 1993 yielded only four individuals of *G. mnesampela* and one of *C. micra* and neither species was hyperparasitised (Table 2). The collection of *M. privata* larvae prevented hyperparasitism of parasitoid cocoons and probably limited hyperparasitism via the larval host. However, none of the larvae collected in their fourth or fifth instar (28%) contained secondary parasitoids, suggesting that the frequency of hyperparasitoids was very low at this site. Fifty-six percent of pupae resulting from collected larvae died before mid January 1994, 34% pupated successfully

to adult *M. privata* and 10% resulted in the emergence of *H. scaposum*. Thus, the larval-pupal parasitoid *H. scaposum* was the most successful parasitoid attacking larvae at Lyneham Ridge in 1993.

Host age preference

Three larvae collected in their second or third instar yielded *G. mnesampela* in the fourth instar (Table 2). This result shows that *G. mnesampela* can parasitise second instar hosts. The possibility that first instar hosts can be parasitised was not confirmed and insufficient parasitoids were reared to determine if later host instars are also vulnerable. The host age preference of *C. micra* is unclear as only one host larva, collected in its fourth instar, was parasitised. *Heteropelma scaposum* were observed attempting to parasitise both early- and late-instar larvae of *M. privata* in the field. However, percent parasitism by *H. scaposum* did not increase significantly with host age suggesting that parasitisation of later instars was not as successful (Table 3).

TABLE 3. Percent emergence of the larval-pupal parasitoid, *Heteropelma scaposum*, in relation to the instar at which its host, *Mnesampela privata*, was collected Lyneham Ridge (Canberra, ACT.)

Instar of <i>M. privata</i> at collection	No. pupae	% emergence		
		<i>H. scaposum</i>	<i>M. privata</i>	No emergence
2	57	11	32	58
3	73	10	38	52
4	50	10	32	58
5	29	10	34	55

TABLE 4. Effect of the outcome of pupae on the weight of pupae of *Mnesampela privata* three days after pupation. ^a $p < 0.05$; Scheffé's test of multiple contrasts.

Outcome	Mean weight \pm SE (mg)	F
Adult male <i>M. privata</i> v. adult female <i>M. privata</i>	149 \pm 3.7 v. 127 \pm 3.2	17.68*
Male pupae that died v. female pupae that died	130 \pm 3.1 v. 109 \pm 2.6	26.63*
Adult <i>M. privata</i> v. pupae that died	140 \pm 2.8 v. 119 \pm 2.2	31.89*
Adult <i>M. privata</i> v. adult <i>H. scaposum</i>	140 \pm 2.8 v. 142 \pm 5.8	0.46
Adult <i>H. scaposum</i> v. pupae that died	142 \pm 5.8 v. 119 \pm 2.2	17.44*

Pupal weight

The outcome of pupae (categorised by the emergence of either a male or female adult *M. privata*, an adult *H. scaposum* or the death of the pupae) significantly influenced the weight of pupae at pupation ($F = 22.9$; $df = 4, 200$; $p < 0.001$). Pupae that died were significantly lighter than both pupae that successfully produced adult *M. privata* and

parasitised pupae resulting in adult *H. scaposum* (Table 4). Pupae resulting in adult female *M. privata* were significantly heavier than those resulting in males. However, the weights of pupae resulting in adult *H. scaposum* were not significantly different from those of pupae resulting in adults of *M. privata* (Table 4). The sex ratios of pupae of *M. privata* (not including pupae that resulted in *H. scaposum*) and *M. privata* that emerged as adults were 1:1.04 ($n = 188$) and 1:1.33 ($n = 72$) (male : female) respectively. Neither ratio was significantly different from 1:1 ($\chi^2 = 0.085$ and 1.389 respectively, $df = 1$, $p > 0.05$). Successful pupation was independent of the sex of the pupa ($\chi^2 = 1.61$; $df = 1$; $p > 0.05$).

Biology of parasitoids

Family Braconidae

Cotesia geometricae Austin sp. nov.

&

Glyptapanteles mnesampela Austin sp. nov.

(FIGS 5, 9, 10)

All known species of the microgasterine genera *Cotesia* and *Glyptapanteles* are endoparasitoids of macrolepidopterans (Austin & Dangerfield 1992) although there is no previous record of either genus parasitising larvae of *M. privata*. The species reared during this study are unknown and described below as two new species. *Cotesia* and *Glyptapanteles* can be easily recognised from other parasitoids associated with this host by the absence of venation in the distal part of the fore wing, the absence of vein 2mcu (Fig. 5), their small size and dark colour. Superficially, they are similar to each other and could be easily misidentified as a single species. However, the shape and sculpturing of the first and second metasomal tergites can be used to readily separate them (Figs 9, 10) (see descriptions below for further detail).

Glyptapanteles mnesampela can parasitise second instar larvae of *M. privata* although it is not known if first or later instars are also vulnerable. Final-instar larvae of *G. mnesampela* and *C. geometricae* emerge from the penultimate or final instar of *M. privata*, aggregate and pupate near the host remains. This life history is consistent with other members of *Glyptapanteles* and *Cotesia* except that not all species in these two genera are gregarious; some are known to be solitary (Austin & Dangerfield 1992). Adult *C. geometricae* emerged 13–24 days after the collection of their cocoons at the field site in Altona, Victoria (Fig. 1).

Family Ichneumonidae

Casnarina micra Jerman & Gauld

(FIGS 3, 12)

All known species of *Casnarina* are solitary endoparasitoids of lepidopteran larvae. This study

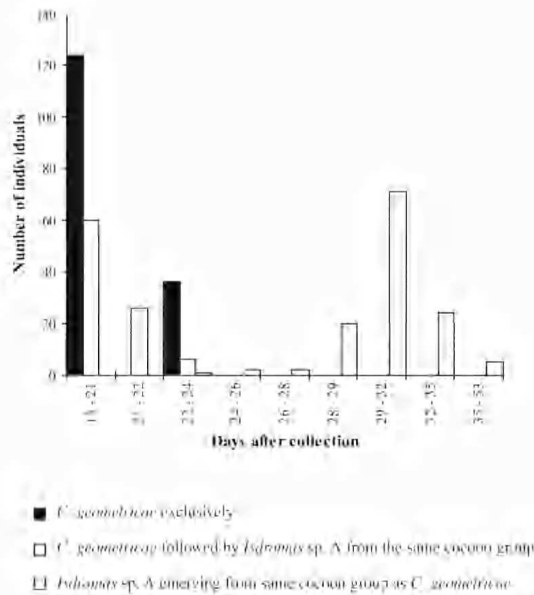


Fig. 1. Temporal pattern of emergence of the gregarious, primary parasitoid *Cotesia geometricae* sp. nov. and its hyperparasitoid *Isidorius* sp. A, from groups of cocoons associated with the larvae of *Mnesampela privata* (Guenée) collected at Altona, Victoria.

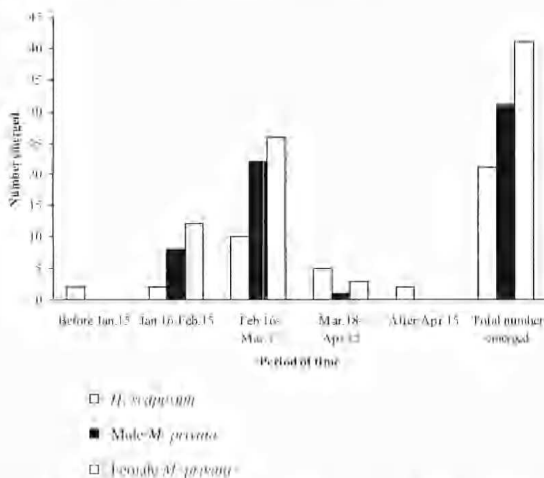


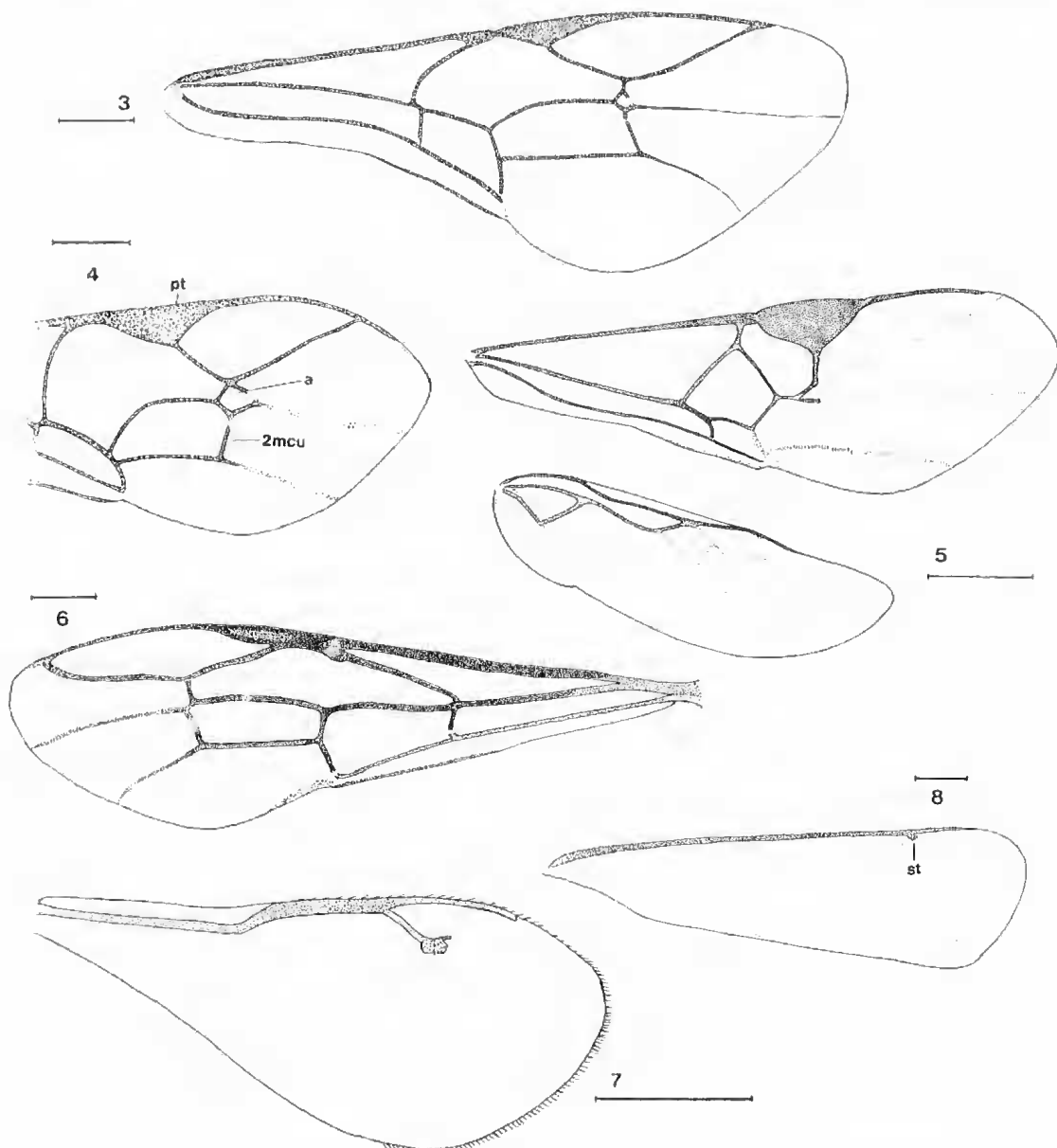
Fig. 2. Temporal pattern of emergence of adult *Mnesampela privata* (Guenée) and the larval-pupal parasitoid *Heteropelma scaposum* (Morley).

provides the first record of *C. micra* reared from *M. privata*. Specimens of a *Casinaria* were reared from *M. privata* larvae collected by Elliott and Bashford (1978) but were not identified to species. In this study, *C. micra* killed late-instar larvae. This result differs from that of Jerman and Gauld (1988) who observed *C. micra* killing *Muesampela* (species not specified) in an early instar. However, Allen (1990) found adults of *C. micra* emerging from mid- to late-instar larvae of *Uraba lugens* Walker (Noctuidae).

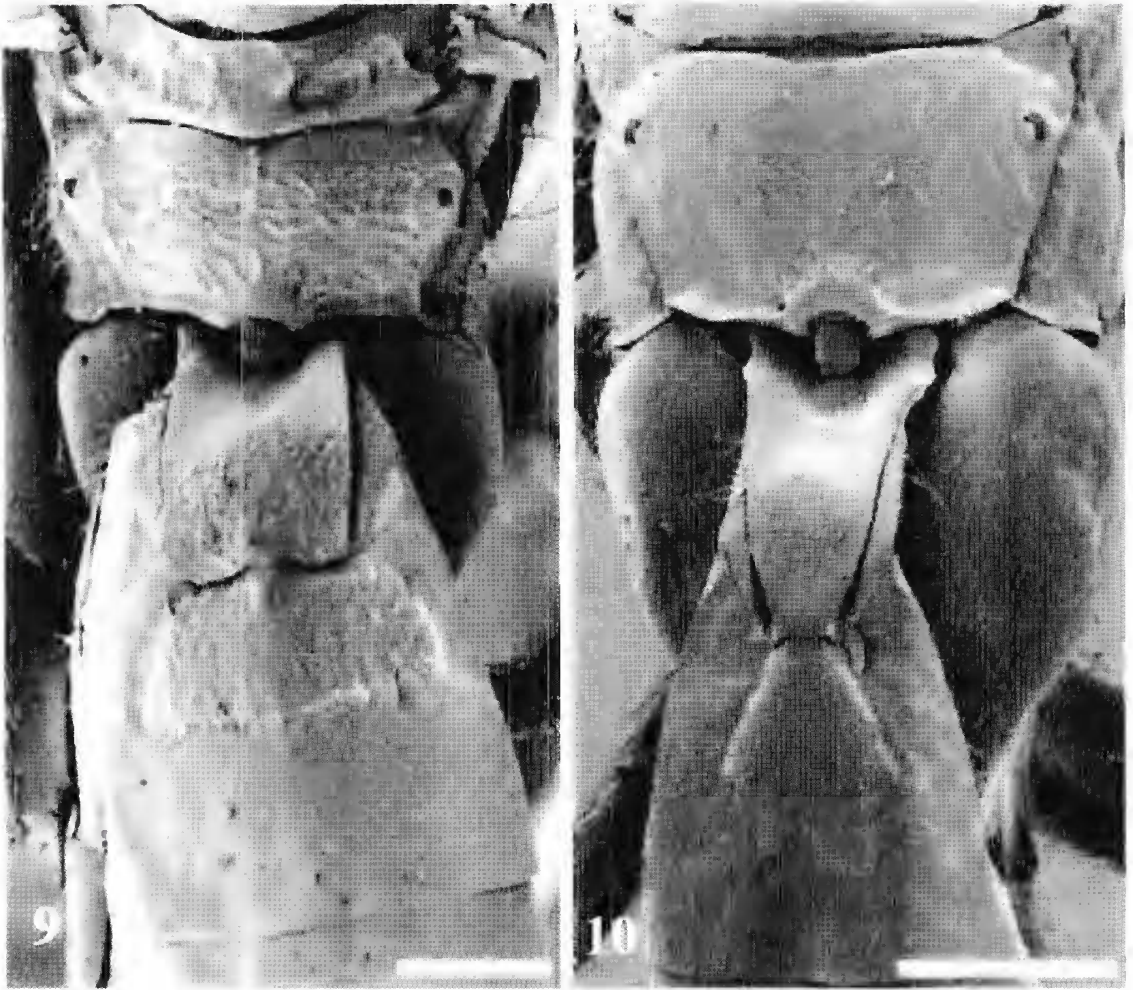
The specimens reared from cocoons in Victoria were all solitary emergences which occurred 15-27 days after collection.

Heteropelma scaposum (Morley)
(FIGS 6, 14)

This species is a common solitary larval-pupal parasitoid with numerous host associations including *Pararguda australasia* (F.) (formerly *Digglesia*



Figs 3-8. Wings. Fig. 3. *Casinaria micra* Jerman & Gauld. Fig. 4. *Mesochorus* sp. Fig. 5. *Glyptapanteles muesampela* sp. nov. Fig. 6. *Heteropelma scaposum* (Morley). Fig. 7. *Megadicylus* sp. Fig. 8. *Elasmus* sp. Scale bars = 0.5 mm 3-5, 7; 1.0 mm 6; 200 μm 8. Abbreviations: a = arcolet; pt = pterostigma; st = stigmal vein.



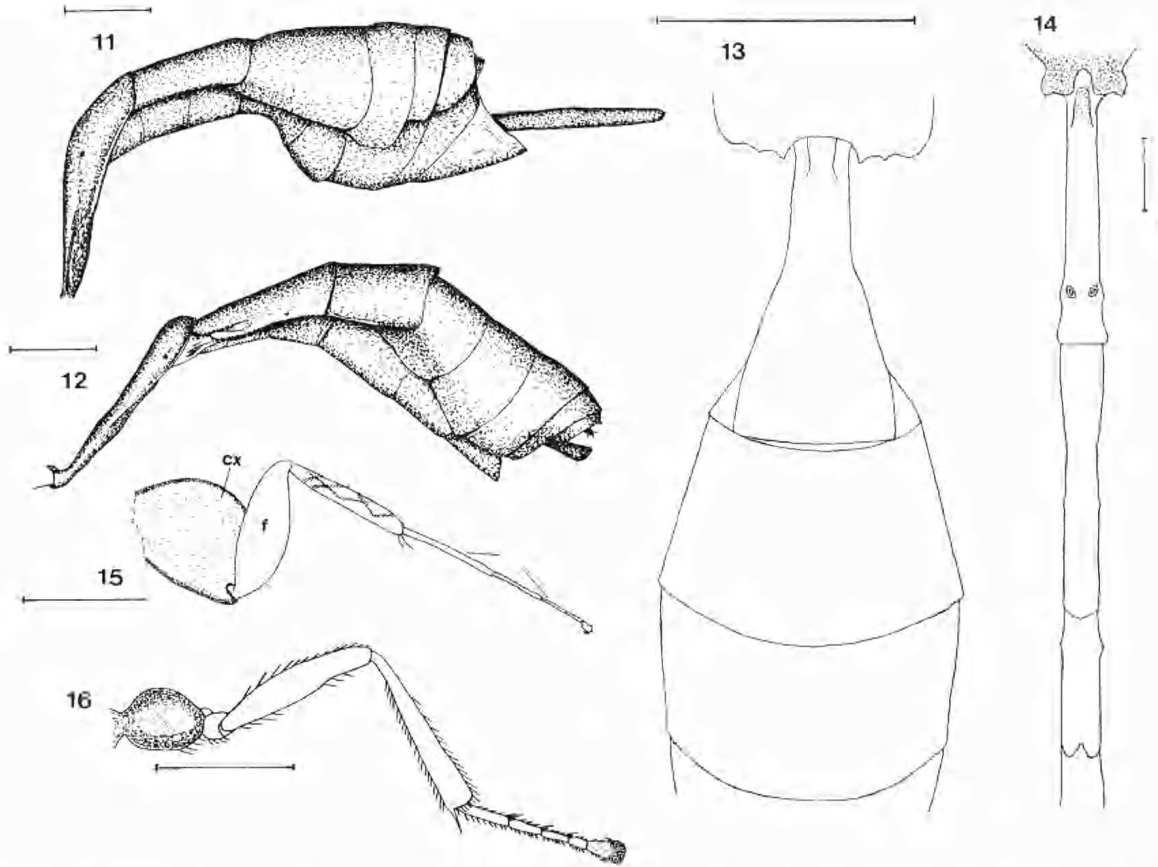
Figs 9, 10. Propodeum and metasomal tergites 1-3. Fig. 9. *Cotesia geometricae* sp. nov. Fig. 10. *Glyptapanteles muesampela* sp. nov. Scale bars = 100 μ m.

australasia) (Lasiocampidae) and the agricultural pests *Helicoverpa armigera* (Hübner) and *Spodoptera litura* F. (Noctuidae) (Gauld 1984). In these associations *H. scaposum* parasitises its host in an early instar (Gauld 1984). It has previously been identified as a larval-pupal parasitoid of *M. privata* in Tasmania and Victoria (de Little 1981¹; Lukacs 1999²). In this study, *H. scaposum* appeared to be most successful in parasitising early-instar larvae (Table 3). This is consistent with early instars of *M. privata* not forming protective leaf bags and thus being more vulnerable to parasitoid attack and with the fact that larger late-stage larvae exhibit more effective defensive responses (rearing and regurgitating drops of *Eucalyptus*-scented fluid) (Elliott & Bashford 1978; Schumacher, pers. obs.). In addition, Lukacs (1999²) observed oviposition in

first instar larvae of *M. privata* but none in later instars. Larvae of *H. scaposum* do not develop beyond the first instar until the host pupates (Gauld 1984). The average weight of pupae that yielded *H. scaposum* was not significantly different from that of the mean weight of viable pupae (Table 4), indicating that parasitism by *H. scaposum* does not influence the behaviour or growth of larval hosts. The temporal patterns of emergence of male and female *M. privata* and *H. scaposum* were similar (Fig. 2) with most emerging between mid-February and mid-March.

Isdromas spp.
(FIG. 13)

Isdromas species are commonly reared as hyperparasitoids from small ichneumonid or



Figs 11, 12, Lateral metasoma. Fig. 11, *Mesochorus* sp. Fig. 12, *Casinaria micra* Jerman & Gauld. Figs 13, 14, Dorsal metasoma (sculpturing not shown). Fig 13, *Isdromas* sp. A. Fig. 14, *Heteropelma scaposum* (Morley). Figs 15, 16, Hind leg. Fig. 15, *Elasmus* sp. Fig. 16, *Megadicylus* sp. Scale bars = 1.5 mm 11, 12; 0.5 mm 13, 15, 16; 1.0 mm 14. Abbreviations: cx = coxa, f = femur.

braconid cocoons, particularly from microgasterine braconids, although they are also recorded as primary parasitoids of a range of lepidopteran hosts (Gauld 1984). There are about 30 species known from Australia, all except three are undescribed including the two species reared during the present study. There is no doubt that they are hyperparasitoids in the cocoons of *C. geometricae* (Table 1), given that no other cocoons were present and the larval cadavers of *M. privata* were not left in the rearing vials. The peak of the subsequent emergence of *Isdromas* sp. A occurred 11-16 days after *C. geometricae* emergence (Fig. 1).

Mesochorus sp.
(FIGS 4, 11)

Mesochorus spp. are hyperparasitic on the endophagous larvae of Braconidae and Tachinidae (Gauld 1984). Within lepidopteran hosts, mesochorines will often attack gregarious endo-

parasitoids, especially microgasterine braconids (Gauld 1984; Allen 1990). In this study *Mesochorus* sp. was reared from cocoons of *C. geometricae*. Species of *Mesochorus* also parasitise *Cotesia urabae* Austin & Allen (Braconidae) and *C. micra* via *U. lugens* (Austin & Allen 1989; Allen 1990), as well as the tachinid parasitoids of *Paropsis atomaria* Olivier (Coleoptera: Chrysomelidae) (de Little 1982) and *Perga* spp. (Hymenoptera: Pergidae) (Came 1969).

Family Elasmidae
Elasmus sp.
(FIGS 8, 15)

Members of this genus are obligate hyperparasitoids of Lepidoptera. One species, *E. australiensis* Girault, has been reared from *C. micra* and two microgasterine braconids via *U. lugens*. In this study only three specimens of *Elasmus* sp. were reared from *C. geometricae* via *M. privata* and they

may be similarly parasitic on *C. micra* although this association was not confirmed.

Family Pteromalidae

Megadielys sp.
(FIGS 7, 16)

Megadielys spp. are primary parasitoids of lepidopteran larvae and pupae in cocoons, or are hyperparasitoids on them. They have previously been associated with several lepidopteran families, as well as microgastrine braconid cocoons (Bouček 1988). This is the first record of a species being reared from *M. privata*. It is most likely a hyperparasitoid of *C. geometricae* as no other cocoon types were noticed and the cadavers of *M. privata* larvae were not left in the rearing vials. Only one species has been recorded from Australia, *M. dubius* (Girault) but the association with *M. privata* has not been confirmed as this species.

Other parasitoids associated with
Mnesampela privata
(Ichneumonidae and Tachinidae)

Apart from the species discussed above a number of other parasitoids has been previously reared from *M. privata* but these were not recorded in the present study. They include the ichneumonids *Eriborus* sp., *Megaceria pagana* (Morley), *Prisliceros* sp., *Campoplex* sp. and ?*Anacris* sp., and an unidentified tachinid fly (Elliott & Bashford 1978; de Little 1981; Gauld 1984; Lukacs 1999²) (Table 5). Of these species, all have been reared from *M. privata* in Tasmania with the exception of *M. pagana* which is known only from Victoria (Gauld 1984). However, Gauld (1984) recorded an unknown species of *Megaceria* from *M. privata* in Tasmania and it is very likely to be this species. Based on the biology of other species belonging to these ichneumonid genera, all of them are probably solitary primary endoparasitoids (Gauld 1984). We have not been able to examine material of these species and so have not included them in the key, although their distribution and biological characteristics are compared with the species recorded in the present study in Table 5.

Key to the parasitoids of *Mnesampela privata* at
the three study sites

1. Fore wing with relatively complete venation (Figs 3-6); small to large species, > 2.5 mm in length 2
2. Fore wing with pigmented venation reduced to anterior margin (Figs 7, 8); minute to small species, < 2.5 mm in length 8
3. Fore wing with venation distal to pterostigma wanting (Fig. 5); vein 2mCu absent (Braconidae) 3
3. Fore wing with distal veins present and well-pigmented; vein 2mCu present (Figs 3, 4, 6) (Ichneumonidae) 4
4. Propodeum and metasomal tergites 1 and 2 virtually smooth; tergite 1 narrowing apically; tergite 2 with subtriangular median field (Fig. 10) *Glyptapanteles mnesampela* sp. nov.
5. Propodeum and metasomal tergites 1 and 2 with obvious dense punctation; tergite 1 moderately broad, parallel-sided; tergite 2 broad and rectangular (Fig. 9) *Cotesia geometricae* sp. nov.
5. Fore wing with an areolet (Figs 3, 4) 5
6. Fore wing without an areolet (Fig. 6) 6
7. Scutum and propodeum densely punctate or rugulose; ovipositor very short, not protruding past posterior metasomal tergites (Fig. 12) (body 7-8 mm in length, dark brown to black, legs reddish; ♂ genitalia without pair of long rods) *Casinaria micra* Jerman & Gauld
8. Scutum and propodeum generally unsculptured (except for propodeal carinae and micropunctures associated with pilosity); ovipositor about 1/3 to 1/2 length of metasoma (Fig. 11) (body 3-4 mm in length, yellow brown with darker markings; ♂ genitalia with pair of long rods protruding posteriorly) *Mesochorus* sp.
9. Metasomal tergite 1 narrow and very elongate (Fig. 14); fore wing with radial cell elongate (Fig. 6) (♀ body length about 20 mm, ♂ 10-12 mm; head and mesosoma black, legs and metasoma yellow to orange-brown) *Heteropelma scaposum* (Morley)
10. Metasomal tergite 1 broadening apically (Fig. 13); fore wing with radial cell short and broad (body length 2.3-3.2 mm not including ♀ ovipositor; head and mesosoma black, metasoma either dark or yellow with dark markings) (*Isdromus* spp.) 7
11. Scutum smooth; fore wing stigma of ♀ clear in posterior half, white anteriorly; ♂ evenly translucent; legs yellow; metasoma either dark and sometimes with lighter transverse bands at sutures or yellow with darker markings *Isdromus* sp. A
12. Scutum with dense punctate sculpturing; fore wing stigma of ♀ and ♂ evenly dark; fore and mid legs light brown, hind legs dark brown; metasoma dark brown to black *Isdromus* sp. B
13. Hind coxa developed as large flat disc; hind tibia with distinct criss-cross pattern of setae (Fig. 15); fore wing with stigmal vein very short (Fig. 8); body dark, tegula and legs

TABLE 5. Comparison of larval and larval-pupal parasitoids associated with *Mnesampela privata* at different locations in Australia. Sources of data: ^aElliott & Bashford 1978, ^bde Little 1981, ^cGauld 1984, ^dLukecs 1999; this study. la = low altitude (< 500 m asl), ha = high altitude (> 500 m asl). *Species not identified.

Host stage attacked / emerged	Family	Parasitoid species										
		S Tas. ^a (la)	NW Tas. ^b (ha)	Tas. ^c	Central & NW Tas. ^d (ha)	Vic. ^c	S Tas. (la) & Vic. ^d	S Vic. ^c	ACT ^e			
Primary parasitoid of early instar / L4-5	Braconidae	-	-	-	-	-	-	-	-	<i>Cotesia geometricae</i>	<i>Cotesia geometricae</i>	
		-	-	-	-	-	-	-	-	-	<i>Glyptapanteles mnesampela</i>	
Primary parasitoid of L? larva / L?	Ichneumonidae	-	-	-	-	-	-	-	-	<i>Casiniaria mitra</i>	<i>Casiniaria mitra</i>	
		<i>Casiniaria</i> sp.	-	-	-	-	-	-	-	-	-	
Primary parasitoid of L? larva / pupa	Ichneumonidae	<i>Eriborus</i> sp.	-	<i>Eriborus</i> sp.	-	-	-	-	-	-	-	
		<i>Campoplex</i> sp.	-	-	-	-	-	-	-	-	-	
Hyperparasitoid of ichneumonid or braconid parasitoids, stage unknown / parasitoid pupa	Ichneumonidae	-	<i>Heteropelma scapostum</i>	<i>Megaceria</i> sp.	<i>Heteropelma scapostum</i>	<i>Megaceria pagana</i>	<i>Heteropelma scapostum</i>	<i>Heteropelma scapostum</i>	<i>Heteropelma scapostum</i>	pupae not reared	<i>Heteropelma scapostum</i>	
		-	Unidentified	<i>Pristiceros</i> sp.	? <i>Atacis</i> sp.	-	? <i>Atacis</i> sp.	-	-	-	-	
		*1 sp.	*1 sp.	-	*1 sp.	-	-	-	-	-	pupae not reared	
Obligate hyperparasitoid of braconid parasitoids, stage unknown / parasitoid pupa	Ichneumonidae	-	-	-	-	-	-	-	-	-	-	
		-	-	-	-	-	-	-	-	-	2 spp. of <i>Isdromus</i>	
Hyperparasitoid via lepidopteran host, stage unknown / parasitoid pupa	Elasmidae	-	-	-	-	-	-	-	-	-	<i>Mesochorus</i> sp.	<i>Elasmus</i> sp.
Parasitoid pupa	Pteromalidae	-	-	-	-	-	-	-	-	-	-	<i>Megadicyllus</i> sp.

2.7 mm, ♂ 1.3-1.9 mm) (Elasmidae).....
*Elasmus* sp.
 Hind coxa normal size; hind tibia without
 criss-cross pattern of setae (Fig. 16); fore wing
 stigmal vein elongate (Fig. 7); body vivid
 iridescent green or blue-green (♀ body length
 3.2 mm, ♂ 2.3 mm) (Pteromalidae).....
*Megadicylus* sp.

Description of new species

Cotesia geometricae Austin sp. nov.
 (FIG. 9)

Holotype: ♀, Victoria, Altona, Dow Chemical Plant,
 10.ix.1992, ex *Muesampela privata* (ANIC).

Paratypes: 25 ♀♀, 10 ♂♂, same data as holotype
 but 10.ix.1992 and 8.vii.1994 (ANIC, WARI); 10
 ♀♀, 2 ♂♂, Lyneham Ridge, Canberra, ACT (ANIC,
 WARI).

Female

Length: 2.9 mm.

Colour: Head black; face, vertex and occiput with
 dull lustre; antennae and mesosoma black; coxae
 black, legs yellow-brown, apex of hind femur and
 tibia sometimes with darker patch, tarsi black;
 metasoma black except for laterotergites of segments
 1-3 which are yellow-brown; wings hyaline, stigma
 uniformly dark as are fore wing veins C+Sc+R, 1-
 R1, r and 3-Rs, these veins being darker than the rest.

Head: Face, temples and lateral frons with fine,
 dense punctation associated with pilosity; medial
 frons and vertex between ocelli smooth and hairless;
 eyes densely covered with hairs, face slightly
 narrower than half width of head (3.1:6.5), inner
 margins of eyes adjacent to face evenly curved and
 slightly converging ventrally; ocelli large, forming
 slightly obtuse triangle, lateral ocelli separated by
 distance from lateral ocellus to eye margin; antennae
 moderately long, about as long as body.

Mesosoma: Scutum with fine, dense punctation
 associated with dense pilosity, posterior half with
 smooth medial longitudinal line; notauli only very
 faintly indicated by shallow depressions; dorsal
 scutellum smooth except for a few scattered
 punctures along lateral margins; lateral band of
 scutellum very broad and smooth; metanotum not
 fitting against posterior scutellum so that phragma
 of scutellum exposed laterally; propodeum coarsely
 rugulose-punctate, with slight mid longitudinal
 depression and a few short striae radiating from
 ventral margin; lateral pronotum with deep dividing
 grooves which are very slightly punctate; meso-
 pleuron with fine punctation associated with pilosity
 in anterior half and ventrally below precoxal groove,

the rest smooth and shining; precoxal groove finely
 punctate; hind coxa finely punctate in anterior $\frac{2}{3}$ and
 associated with dense pilosity.

Wings: Fore wing stigma broad, 2.3 x as long as
 broad; hind wing broad, vannal lobe convex with
 long marginal fringe of hairs throughout.

Metasoma: T1 slightly longer than wide (3.3:2.9),
 virtually parallel-sided, smooth in anterior half,
 rugulose-punctate in posterior part but much finer
 compared with propodeum; T2 subrectangular, 2.3 x
 as wide as long, lateral margins curving inwards in
 anterior part, surface rugulose-punctate but slightly
 less coarse than on anterior part of T1, longitudinal
 mid-line slightly raised and smoother than lateral
 areas, posterior and lateral margins with single line
 of more distinct punctures; length of T2-T3 1.6:2.0;
 length of T2-T4 equal; T2-T6 smooth and shining,
 with long scattered hairs along posterior margin;
 hypopygium with a few scattered long hairs,
 posterior margin straight to very slightly concave;
 ovipositor sheaths very short and straight, with a few
 long apical hairs.

Male

As for female.

Host

Reared from *Muesampela privata* (Geometridae).

Comments

The sculpturing on the propodeum and T1-T3, the
 shape of these sclerites, the form of the hypopygium
 and ovipositor, clearly place this species in the genus
Cotesia Cameron. *Cotesia* has previously been
 referred to as the *glomeratus* species-group of
Apanteles s.l. (see Mason 1981; Austin &
 Dangerfield 1992) and it is the largest genus of
 Microgastrinae, comprising hundreds of species
 world-wide. In Australia the genus is both common
 and diverse but other than several species introduced
 from Europe and North America as biological
 control agents for certain lepidopteran pests (see
 Austin & Dangerfield 1992), the Australian fauna
 remains virtually unstudied. One other species, *C.*
urabae Austin & Allen, is also associated with a
 eucalypt-feeding host viz. *Uraba lugens*. *Cotesia*
geometricae differs from this species in that it is
 gregarious, the first metasomal tergite is parallel-
 sided (not broadened posteriorly), the first and
 second tergites are more finely sculptured, the
 median field of the second tergite has rounded
 anterior corners (not angled anteriorly) and the third
 tergite is smooth throughout (not sculptured
 anteriorly). This species is named after the family of
 its host.

Glyptapanteles mnesampela Austin sp. nov.
(FIGS 5, 10)

Holotype: ♀, Australian Capital Territory, Lyneham Ridge, 30.iii.1993, ex *Mnesampela privata* 22.vi.1993 (ANIC).

Paratypes: 1 ♀, 3 ♂♂, same data as holotype (ANIC, WARI).

Female

Length: 2.5 mm.

Colour: Head, antennae and mesosoma black but propleuron yellow-brown; fore and mid legs yellow-brown, including coxae, tarsi darker; hind femur and tibia yellow-brown, coxae black, tarsi darker than tibia, distal tibia black; dorsal metasoma yellow-brown in anterior half, black posteriorly, ventral metasoma yellow-brown in anterior two-thirds, black posteriorly; wings hyaline, venation moderately dark, stigma uniformly dark.

Head: Face, temples and lateral frons smooth except for scattered micropunctures associated with hairs; medial frons, vertex between ocelli and occiput smooth and hairless; eyes densely covered with hairs, face slightly narrower than half width of head (2.6:5.8), inner margins of eyes adjacent to face evenly curved; ocelli forming broad obtuse triangle, lateral ocelli separated by more than distance from lateral ocellus to eye margin; antennae long, much longer than body.

Mesosoma: Scutum finely and discretely punctate medially, becoming more densely punctate-reticulate towards lateral margin, densely covered with hairs; notauli only very faintly indicated by shallow depressions; dorsal scutellum smooth with a few small scattered punctures; lateral band of scutellum very broad; metanotum fitting closely against posterior scutellum, phragma of scutellum only exposed in lateral corners; propodeum smooth with a few small radiating striae postero-medially; anterior half of propodeum with a few hairs and associated micropunctures; mesopleuron smooth, covered with hairs in anterior one-third and ventrally below precoxal groove; precoxal groove unsculptured; hind coxa finely punctate, covered with hairs.

Wings: Fore wing with stigma broad, about 2.5 x as long as broad; base of 2-M pigmented; hind wing broad, vannal lobe convex with long marginal fringe of hairs throughout.

Metasoma: T1 mostly smooth with a few faint striae, lateral margins evenly narrowing, with a few scattered long hairs; median field of T2 delimited laterally and posteriorly by distinct sulci, almost an equilateral triangle in shape, length of T2-T3 1.3:1.6; T2-T6 smooth and shining, T2 without hairs, T3-T6

with long scattered hairs; hypopygium with a few scattered long hairs; ovipositor sheaths very short and straight, with a few long apical hairs.

Male

As for female except as follows: Antennae longer and more robust; head and scutum with denser white hairs; scutum with denser punctation; metasoma all black; hind legs with femur darker or infuscate.

Host

Reared from *Mnesampela privata* (Geometridae), the autumn gum moth.

Comments

Glyptapanteles is a large cosmopolitan genus of several hundred species, which comprises mostly the *viripennis* and *actonarius* species-groups (*sensu* Nixon 1965), as well as a number of smaller groups, all of which are extra-limital except for the monospecific *demeter* group from New Zealand (Nixon 1965; Mason 1981). In Australia and Tasmania there are an estimated 100 plus species of *Glyptapanteles*, only one of which is described, *G. deliata* Austin & Dangerfield. The genus is most diverse in the tropical parts of the continent, and appears to be disproportionately represented in the microgastrine fauna of the south-eastern Pacific, from where a number of aberrant species have been described, e.g. *G. demeter* (Wilkinson) from New Zealand, which is strongly dorso-ventrally flattened and *G. afiamaluana* (Fullaway) from Samoa, which has a complete medial propodeal carina, vasiform T1 and stub of vein 3-Rs present in the fore wing (Austin & Dangerfield 1992).

Glyptapanteles mnesampela can be distinguished from *G. deliata* and most other undescribed Australian species by its colour, shape of metasomal tergites 1 and 2, and sculpturing of the scutum and propodeum. Although the degree of host specificity of *Glyptapanteles* spp. is poorly known, it is also likely that host associations provide a useful initial guide to the identity of many microgastrine parasitoids and this is probably the case for this species. *Glyptapanteles mnesampela* is named after the host genus.

Discussion

This study has expanded the known parasitoid complex of larvae of *M. privata* in south-eastern Australia to include the primary parasitoids *Casinarina miera* and two new braconid species, *G. mnesampela* and *C. geometricae* and five species of hyperparasitoid, in addition to several previously recorded species (Elliott & Bashford 1978; de Little 1981; Gauld 1984; Lukacs 1999) (Table 5). The

parasitoid complex of a host species is often stable between geographical locations when the host feeds on the same (or taxonomically related) plant species (Askew & Shaw 1986; Mills 1993). However, the parasitoids reared from *M. privata* do not appear to follow this generalisation in that the species reared at the two mainland sites (Victoria and the ACT) differed both from each other and from those previously reported from Tasmania and Victoria (Table 5). In particular, *G. mnesampela* has only been found in the ACT but no hyperparasitoids were recorded from this site and are also apparently absent in Tasmania. Two species of larval parasitoid recorded in Tasmania (Elliott & Bashford 1978; Gauld 1984) have not been recorded from the mainland and several larval-pupal parasitoids recorded in Tasmania and Victoria (Elliott & Bashford 1978; de Little 1981; Gauld 1984; Lukaes 1999) were not found in this study. In addition, two different species of primary parasitoid were collected in consecutive years at Lyneham Ridge although it is possible that both species were present during both years but were not found due to the low level of parasitism at the site. In part, differences between parasitoid complexes may reflect collecting bias and an initial naive separation of different parasitoid species in the 1992 Victorian collection (i.e. pupae were not reared and *G. mnesampela* may have been confused with *C. geometriyae*). However, the relative abundance of a host can significantly influence the composition and number of parasitoid species it can support (Mills 1990; Mills & Kenis 1991). The greater species richness of the parasitoid complex found at Altona and to a lesser extent Shepparton, therefore, may also be due to the higher relative host abundance at these locations. The paucity of parasitoids in the de Little (1981) study (Table 5), which was also undertaken during a severe outbreak, may be because only parasitoids seen ovipositing into larvae were identified. Differences in host phenology may also contribute to differences in the make-up of parasitoid complexes (Askew & Shaw 1986). Although most populations of *M. privata* have a dominant autumn—winter population (McQuillan 1985) and an almost insignificant summer population (Lukaes 1999), the latter study found that populations at higher altitudes in Tasmania (> 500m asl) can also have a large summer—autumn population and are potentially bivoltine. With this in mind it should be noted that the survey by de Little (1981) was made during a summer outbreak at a high altitude location in NW Tasmania whereas Elliott & Bashford (1978) and this study examined lower altitude populations present over autumn and winter (N.B. Lukaes (1999) did not differentiate between summer and autumn populations of host larvae or specifically record the altitude of the

collecting sites). Further investigation of the influence of temporal and geographical variation of host abundance on the composition of the parasitoid complex utilising larvae of *M. privata* will be required to clarify these discrepancies.

This study found that *M. privata* had an equal sex ratio at both pupation and emergence. However, although the present results did not show a significant departure from a 1:1 sex ratio, the trend towards a greater proportion of female adults resembles that found by Elliott & Bashford (1978) who obtained 64% female adults from reared larvae. The significantly lower weight of pupae that died suggests that larvae must achieve some critical weight to survive the pupal period. The degree of overlap of weights between viable male and female pupae of *M. privata* indicates that prediction of sex based on weight is not feasible.

The primary parasitoids of *M. privata* larvae recorded in this and other studies (Elliott & Bashford 1978; de Little 1981; Gauld 1984; Lukaes 1999) kill their host in late instars or as pupae. These parasitoids may reduce defoliation to some extent as larvae are most destructive in their fourth and fifth instars (Elliott & Bashford 1978). However, in addition to their effect during the current season, larval parasitoids may reduce the number of *M. privata* that emerge in the next generation. The potential role of these parasitoids in biological control, therefore, is likely to be one of regulation and prevention of outbreaks rather than as a method of control when an outbreak is occurring.

Although the causes of outbreaks of *M. privata* are unclear it appears that large monocultures of genetically similar species are especially vulnerable (Neumann & Collett 1997). The ineffectiveness of parasitism in such situations (Elliott & Bashford 1978; de Little 1981; Neumann & Collett 1997) may be due to low numbers of natural enemies limited by the lack of alternative food sources, coupled with rapid population growth of the insect herbivore in an area of dense and abundant resources (Root 1973; Altieri & Letourneau 1984; Altieri *et al.* 1993). In addition, the use of non-specific insecticides will curtail the numerical response of larval parasitoids and thus prevent their contribution to stabilising host populations.

Research into the sustainable management of pest insects is seen as an important step to improve the currently poor economic returns from eucalypt forests (Stone 1993). Current research in Australia has included the evaluation of strains of *Bacillus thuringiensis* Berliner (Harcourt *et al.* 1996; Neumann & Collett 1997), the use of naturally resistant species and provenances of *Eucalyptus* (Farrow *et al.* 1994) and interactions between the scoliiform egg parasitoid, *Tetramesa* sp., and its host

M. privata (Schumacher 1997; Lukaes 1999). The effect of augmenting or encouraging natural populations of larval and egg parasitoids of *M. privata* through practices such as the use of selective insecticides and the provision of alternative food sources for adult parasitoids has not been investigated, although the benefits of such practices have been shown in eucalypt plantations in South America (Bragança *et al.* 1998) as well as other pest-parasitoid systems (Idris & Grafius 1995; Orr & Pleasants 1996). The accurate identification of the natural enemies of *M. privata* and an understanding of their ecology will be essential to the success of such research in Australia.

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